Marine Physical Laboratory

Waveguide Invariants and Space-Frequency Time Signal Processing

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The objectives of this program were to develop and test new signal processing algorithms based on waveguide invariants for use in three challenging ocean acoustic scenarios: 1) range-dependent environments, 2) signals with low signal-to-noise ratio (SNR), and 3) acoustically cluttered conditions.

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OBJECTIVES

The objectives of this program were to develop and test new signal processing algorithms based on waveguide invariants for use in three challenging ocean acoustic scenarios: 1) range-dependent environments, 2) signals with low signal-to-noise ratio (SNR), and 3) acoustically cluttered conditions.

WORK COMPLETED

- Waveguide invariant-based algorithms that are applicable to range and azimuth varying environments have been developed. These algorithms have been applied to shallow water environments, i.e., ones in which both waveguide boundaries are formed by reflection, and where the range and azimuth dependence is associated with varying ocean bathymetry. The algorithm predictions have been compared with actual shallow water acoustic data from the SWellEx-3 experiment. Results have been published (Publ. 1).

- The CASS/GRAB sonar prediction code has been acquired and installed on the computer system at MPL. An algorithm to calculate the standard waveguide invariant with a ray-based propagation code has

been developed and implemented in a computer code interfaced with CASS/GRAB. The normal mode code Kraken, developed by Mike Porter, also has been modified to calculate the invariant. In addition, a stand-alone program based on a ray theory approach has been created to perform this calculation. The values output from these three codes have been inter-compared and have been compared to analytical expressions in canonical environments. The results have been documented and submitted for publication in the Journal of Underwater Acoustics (Publ. 5). A computer code to calculate the invariant in spatially varying shallow water environments also has been created.

- Invariant techniques have been applied to striation patterns found in broadband ambiguity surfaces from matched field processing. These results are published in Publ. 2. The same approach has been applied to the simpler case of broadband sidelobe behavior in conventional plane wave beam forming.

- Invariant techniques have been used to explain the existence and usefulness of focus regions in single element spectrograms recorded in the deep ocean. Results using data from the Acoustic Thermometry of Ocean Climate (ATOC) program have been published (Publ. 3).

- Striation patterns resulting from application of conventional plane wave beam forming to vertical array data (both simulated data and actual vertical hydrophone array data) for both shallow and deep water environments have been studied from a waveguide invariant point of view. Some results are contained in Publ. 4 and were presented at the Fall, 2000, Acoustical Society of America meeting (Ref. 1).

- Existing data from the SACLANT Centre's 254-m horizontal towed array have been acquired (thanks to Martin Siderius and Tuncay Akal) and data processing has been completed. In addition, we actively participated with Martin Siderius in his experiment with the Centre's towed array in November/December, 2000, and were given 2 days to conduct towed array/broadband source measurements of direct application to this program.

- Interference patterns in towed array beam spectrograms with varying subaperture length have been analyzed to determine the optimal trade-off between physical aperture, synthetic aperture, and array gain.

• Additional data sets of relevance have been acquired and processed to test algorithms developed in this program.

RESULTS

Analytical predictions using the waveguide invariant approach, modified to incorporate range and azimuth dependence in environmental conditions, show very good agreement with striations in single element spectrograms from shallow water acoustic data collected in SWellEx-3 (Publ. 1).

Calculations of the standard waveguide invariant using a stand-alone ray-based code, an algorithm that uses the output from the OAML-approved CASS/GRAB propagation code, and those from the Kraken normal mode code show good agreement, and good agreement with analytical results in canonical environments (Publ. 5).

Sidelobe behavior in broadband ambiguity surfaces from matched field processing can be used to locate underwater sources independent of the main lobe. An analogous result is obtained for estimating the bearing to a source in the simpler case of the broadband sidelobe behavior in conventional plane wave beamforming (Publ. 2).

Focus regions exist in single element spectrograms recorded in the deep ocean that correspond to transitions from one type of propagation to another. These focus regions, along with sound speed information obtained from climatological data bases, can be used to estimate the range to a very-long-distant (Megameter) source (Publ. 3).

The behavior of striations in the vertical wavenumber/range/frequency plane using conventional plane wave beamforming with vertical array data is analytically predicted by an invariant approach in shallow water environments. The striation patterns in the vertical wavenumber/range plane at fixed frequency, as well as in the range/frequency plane at fixed vertical wavenumber, also contain extractable information on source location. For deep water environments, although the striation behavior is more complicated than can be predicted by a strictly invariant approach, some aspects still can be successfully modeled (Publ. 4).

Spectrograms from beams pointed towards a broadband source using both conventional and adaptive plane wave processing with bottom-mounted horizontal array data collected during SWellEx-3 show striation

patterns having the expected array gain and interference cancellation in acoustically cluttered environments. The slope of the interference pattern in the beam spectrograms shows no perceptible distortion from that in the corresponding single element spectrograms in this experimental geometry.

Striation patterns observed in actual ocean acoustic data recorded across the aperture of a horizontal towed array from a broadband source near endfire aft contain robust information on source location in gently range dependent environments. This information can be extracted in an automated way. However, the patterns are significantly degraded when the bathymetry varies strongly spatially.

Analytical expressions that have been derived for the interference patterns measured by acoustic vector sensors and adequately explain their behavior observed in simulation and data.

IMPACT/APPLICATIONS

The waveguide invariant approach has provided a powerful way of examining propagation phenomena in a waveguide. This approach led to novel signal and array processing algorithms. Useful information can be easily extracted from the data from single elements, fixed horizontal bottom line arrays, towed horizontal line arrays, vertical line arrays, and 2D arrays as demonstrated with actual ocean acoustic data.

TRANSITIONS

Transitions have been made, additional transitions presently are in progress, and further transition possibilities are being pursued.

RELATED PROJECTS

1. "Fluctuations and Invariants in Shallow Water," G. L. D'Spain and W. A. Kuperman, sponsored by ONR Code 321 OA. The effects of medium fluctuations on normal mode coupling and the resulting impact on the striation patterns were important issues in both programs.

2. "Passive Synthetic Aperture Sonar (PasSAS)", MPL's Applied Research Laboratory program, sponsored by ONR Code 321 US. Algorithms and techniques developed in the Waveguide Invariants program are directly applicable to the analysis of the low frequency, broadband data collected in the PasSAS program.

3. "MAPEX2000", Martin Siderius, SACLANT Undersea Research Centre. Data collected by the SACLANTCEN's 254-m horizontal towed array have been used to evaluate algorithms based on waveguide invariants.

4. "Mid-Frequency Ambient Noise Spatial Structure and Implications for Passive Signal Processing", W. S. Hodgkiss, G. L. D'Spain, and W. A. Kuperman, sponsored by ONR Code 321 US. Results of analysis of striation patterns in vertical plane wave beamforming developed in the Waveguide Invariants program are being applied in the MF Noise program.

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